The value of ϵ in each case above means the number of 360ths of its period which the corresponding tidal constituent has still to execute till its high-water from the instant when the ideal star crosses the meridian of the place. Thus if n denote the periodic speed of the particular tide in degrees per mean solar hour, its time of high-water is $\frac{\epsilon}{n}$, reckoned in mean solar hours after the transit of the ideal star.

In this definition, and in the table of results, the following notation is employed[1]:—

I to denote the mean inclination of the moon's orbit to the earth's equator during the time of the series of tidal observations included in each instance.

ν ,, ,, the mean right ascension of the ascending node of the moon's orbit on the earth's equator during the same time.

γ ,, ,, the angular velocity of the earth's rotation.

σ ,, ,, the mean angular velocity of the moon's revolution round the earth.

η ,, ,, the mean angular velocity of the earth round the sun.

ϖ ,, ,, the angular velocity of the progression of the moon's perigee.

"Speed" means the angular velocity of an arm revolving uniformly in the period of any particular tidal constituent; each angular velocity being reckoned in degrees per mean solar hour.

[1] The values of I and ν are given to facilitate comparison with the equilibrium values of the several tidal constituents, according to Tables I. and II. of the British Association Tidal Committee's Report of 1876.

THE PHYSICAL FUNCTIONS OF LEAVES

An elaborate study on the above subject has lately been published by Prof. J. Boussingault, of Paris, in the *Annales de Chimie et de Physique* (vol. xiii. pp. 289-394); in which the phenomena of absorption and transpiration by leaves are treated at great length. Since the memorable experiments of Hales in 1727, recounted in his work on "Vegetable Statics," this branch of vegetable physiology has been rarely touched, and the carefully recorded observations of Boussingault, carried out with the best of modern scientific appliances, possess an unusual value.

The first point studied was the loss of water by transpiration from the leaves of plants under normal circumstances. For this purpose a healthy Jerusalem artichoke (*Helianthus tuberosus*) in a roomy flower-pot was chosen. The top of the pot was covered with a sheet of india-rubber, tightly inclosing the stem of the plant, and provided with an opening for the admission of water. The whole was then weighed, and the loss noted which ensued under various circumstances, by evaporation of water from the leaves, the plant receiving during the experiment weighed normal amounts of water. The total surface of the leaves of the plant (both upper and lower sides) was carefully estimated, and the result reckoned on the square metre. The averages of fourteen experiments showed that the artichoke lost hourly, for every square metre of foliage, the following amounts of water:—in the sunshine sixty-five grammes, in the shade eight grammes, during the night three grammes.

In the next place the question was investigated whether the absorption of water by plants, and the ascent of the sap is due to the force resulting from the transpiration on the surface of the leaves, or whether the roots exercise also a certain amount of force to this end. For this purpose experiments similar to the above were carried out with various plants, firstly under normal circumstances, secondly with the stem minus the roots immersed in water. As an instance we can take mint. The plant with roots showed an hourly evaporation per metre, of eighty-two grammes in the sunshine, and thirty-six in the shade. Under the same condition, without roots, the evaporation was sixteen and fifteen grammes respectively.

The results show that the absorption of water by plants is determined in a great measure by the transpiration occurring in the leaves, that this is maintained for a certain length of time without the assistance of the roots, but cannot continue long, being dependent on the injective power possessed by the roots. The effects of pressure on the absorption was next examined, and it was found possible by this means for a time in certain cases to even more than replace the water lost by transpiration. For example: a chestnut branch dipped in water was found to transpire hourly per metre of foliage, 16 grammes. It was then inserted into a tube of water, and subjected to the pressure of a column of water $2\frac{1}{2}$ metres high. Under these conditions the evaporation mounted to 55 grammes per hour, and the branch at the end of five hours weighed more than at the commencement.

The general result of these experiments shows the mutual working of the various parts of the plant with reference to the phenomena of transpiration. The roots absorbing water from the soil by endosmose, direct it towards the stem. Whether the motive force here is injection by the roots or absorption resulting from the transpiration in the green parts of the plant, or a union of both, is a question still unsettled. The stem serves not only as a passage for the water to reach the leaves, but also as a reservoir to be drawn on during rapid evaporation. In the leaves the sap is concentrated by the transpiration, and the matters in solution enter into the cell formation, or, changed by the action of light, are distributed throughout the plant by the descending sap. The circulation would be quite similar to that in an animal, were it not for the irregularity. While the supply of water from the roots varies but slightly, the loss by evaporation from the leaves is subject to the greatest fluctuations, according to the temperature and hygroscopic condition of the surrounding air. During these periods the leaves draw on their stock of constitution water and the supply in the stem; and when both fail, the phenomenon of wilting ensues.

Numerous experiments were made on the difference in *evaporation during the day and during the night.* Those carried out with leaves of the grape vine gave the following hourly averages per square metre of foliage; in sunshine, 35 grammes; in shade, 11; during the night, 0·5. The trellis on which the vine was trained was 1 metre high and 38 metres long, and presented a surface of 138 square metres of foliage. In sunny weather this would lose by evaporation in the course of 24 hours, 48 kilogrammes of water, and nearly half of that amount during cloudy weather. To give an idea of the enormous amount of aqueous vapour dissipated by plants in the sunshine, calculation showed that an acre of beets could lose in the course of 24 hours between 8,000 and 9,000 kilogrammes. Another experiment made with a chestnut-tree $35\frac{3}{4}$ years old showed that it lost over 60 litres of water in the course of 24 hours. The structure of the leaf, however, containing 70-80 per cent. of water, and possessing a thickness frequently of but $\frac{1}{10}$th of a millimetre, would suggest the question why the evaporation is not much more rapid. The answer to this is found in the peculiar structure of the tissue forming the epidermis, designed especially to moderate the transpiration. In order to see the remarkable retentive power exercised by this epidermis, one can expose for a few hours to the sun two cactus leaves of the same superficies, one of which has been deprived of its epidermis. The evaporation in the latter case will be about fifteen times as rapid as in the other. It is the presence of a similar tissue forming the skin of fruits which prevents an otherwise rapid evaporation. For instance, an apple deprived of its skin loses 55 times as much water as a whole specimen in the same time. Losses by rapid evaporation lessen notably the physiological energy of leaves. Thus an oleander leaf containing 60 per cent. of water, when introduced into an atmo-

sphere containing carbonic acid, decomposed 16 c.c. of this gas; one containing 36 per cent. decomposed 11 c.c.; and one containing but 29 per cent. was without action.

A series of observations was made on the relative powers of *evaporation on the upper and lower sides of leaves.* They consisted in plucking two leaves of the same kind at the same moment, covering on the one the upper, on the other the lower side with melted tallow, and then noticing the loss of weight by evaporation in a given time. The average of the results showed that the proportion between the amounts of water evaporated on the upper and lower side of a dozen varieties of leaves was 1 : 4·3. In all cases the amount evaporated from the two exposed sides of two equal leaves was greater than from the entire surface of a similar leaf under the same circumstances.

A point of no small interest with regard to the physical function of leaves is that of their ability to replace the roots of a plant in serving as the agent of absorption. A variety of tests were undertaken to settle this question; among them the following:—A forked branch of lilac (Fig. 1) was so disposed that the one branch was immersed in water while the other was exposed to the ordinary atmospheric conditions. The superficies of foliage was the same on both branches. The transpiration from the surface of the leaves on the latter branch was the same as under normal circumstances, and after the lapse of two weeks the foliage was as fresh as at the commencement, showing that the submerged leaves were fully able to replace the roots in one of their functions. In an experiment with a beet in which one-half of the leaves were in water and one-half in the air, communication being maintained by means of the root, the free portion of the leaves wilted in the course of a day, the neck of the root apparently not offering a sufficient means of communication with the submerged leaves. A grape-vine shoot half plunged in water (Fig. 2) maintained a normal evaporation in the free foliage, and remained fresh for over a month. An oleander shoot under similar conditions maintained its normal appearance for four months. With the artichoke it was found necessary that the surface of the leaves beneath the water should be four times that of the leaves above.

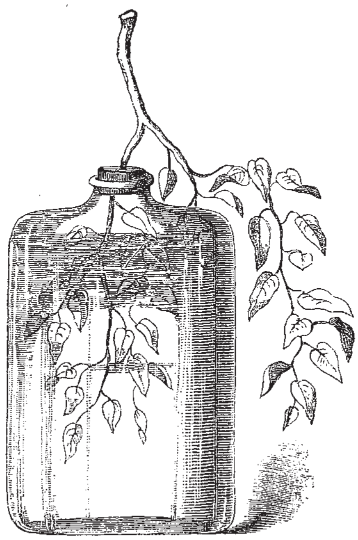

FIG. 1.

Closely bordering on this question is another which has excited much dispute, viz., the ability of leaves to draw water from the surrounding air or by immersion, after having suffered losses by transpiration. Prof. Boussingault's numerous experiments show that leaves, after having been exposed to influences causing a rapid evaporation, are able to absorb water rapidly on immersion, and even from an atmosphere saturated with aqueous vapour. There is, however, in both cases no absorption unless the leaves have lost a portion of their water of constitution, *i.e.*, that which is essential to their normal existence. Thus, a wilted branch of periwinkle weighing 4·0 grammes, after remaining in an atmosphere saturated with aqueous vapour for a day and a half, weighed 4·2 grammes, and after twelve hours' immersion in water 9·4 grammes.

The last function of leaves studied by Prof. Boussingault is their ability to absorb solutions of mineral matter, *i.e.*, perform another of the ordinary duties of the roots. For this purpose a solution of gypsum containing $\frac{2}{1000}$ of solid matter was used. Drops of this solution were placed on the leaves of a great variety of plants—under conditions favouring absorption, as in the experiments just described—and protected from evaporation by superincumbent watch-glasses with greased edges (Fig. 3).

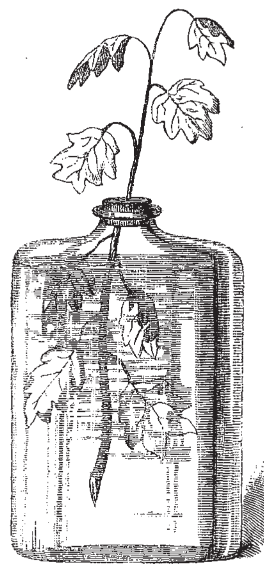

FIG. 2

In most instances the drops were absorbed entirely, leaving no traces of the mineral matter; in some cases a slight residue was left, which the addition of a minute quantity of water caused to disappear. As in the case of pure water, the under side of the leaves absorbed much more rapidly than the upper side. Solutions of sulphate and nitrate of potassium gave quite similar results; the absorption of solutions of chloride of sodium and nitrate of ammonium was not so perfect. These results would tend to show that the foliage of a plant is able to supply it with perhaps no small portion of its saline constituents by means of the ammoniacal salts formed in the air, and the alkaline and earthy salts suspended there which are deposited on the surface of the leaves by rain and dew.

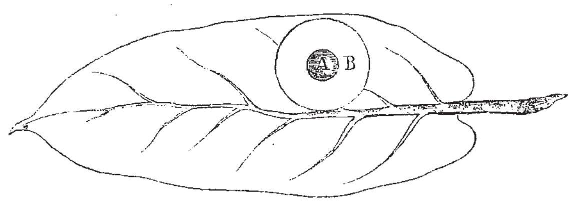

FIG. 3.—A, drop of solution; B, watch glass.

T. H. N.